Attachment C

Radiological Properties for SSL Development

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C.1 Radionuclides Included in Generic Soil Screening Analysis

Principal radionuclides are radionuclides with half-lives greater than six months. The decay products of any principal radionuclide down to, but not including, the next principal radionuclide in its decay chain are called associated radionuclides and consist of radionuclides with half-lives less than six months. It is assumed that a principal radionuclide is in secular equilibrium with its associated radionuclides at the point of exposure. This assumption is reasonable because it usually takes about three years or longer to clean up a site. Principal and associated radionuclides for which generic Soil Screening Levels have been calculated are listed in Table C.1. Associated decay chains are indicated, as well as principal radionuclide half-life and the terminal nuclide or radionuclide (i.e., the principal radionuclide or stable nuclide that terminates an associated decay chain).

Table C.1 Radionuclides Included in Generic Soil Screening Analysis

Principal Radionuclide[a]		Associated Decay Chain[b]	Terminal Nuclide or Radionuclide[c]	
Nuclide	Half-life (yr)		Nuclide	Half-life (yr)
Ac-227+D	22	[Th-227 (98.6%, 19 d) Fr-223 (1.4%, 22 min)] Ra-223 (11 d) Rn-219 (4 s) Po-215 (2 ms) Pb-211 (36 min) Bi-211 (2 min) [Tl-207 (99.7%, 5 min) Po-211 (0.3%, 0.5 s)]	Pb-207	stable
Ag-108m	127	-	Pd-108 (91%) [Cd-108 (98%} Ag-108 (9%) Pd-108 (2%)]	stable stable 2 min stable
Ag-110m	0.7	-	Cs-110 (99%) [Cd-110 (99.7%) Ag-110 (1%) Pd-110 (0.3%)]	stable stable 25 s stable
Am-241	432	-	Np-237	2100000[1]
Am-243+D	7400	Np-239 (2 d)	Pu-239	24000
Bi-207	38	-	Pb-207	stable
C-14	5730	-	N-14	stable
Cd-109	1.3	-	Ag-109	stable
Ce-144+D	0.8	[Pr-244 (9%, 17 min) Pr-244m (2%, 7 min)]	Nd-144	stable
Cl-36	300000	-	S-36	stable
Cm-243	28	-	Am-243 (0.2%)[e]	7400
Cm-244	18	-	Pu-240	6600
Co-57	0.7	-	Fe-57	stable
Co-60	5	-	Ni-60	stable
Cs-134	2	-	Ba-134 (~100%)	stable
Cs-135	3000000	-	Ba-135	stable
Cs-137+D	30	Ba-137m (95%, 3 min)	Ba-137	stable
Eu-152	13	-	Sm-152 (72%) Gd-152 (28%)	stable 1.1E+14
Eu-154	8	-	Gd-154 (~100%)	stable
Eu-155	5	-	Gd-155	stable
Fe-55	3	-	Mn-55	stable
Gd-153	0.7	-	Eu-153	stable
H-3	12	-	He-3	stable
I-129	16000000	-	Xe-129	stable
K-40	1300000000	-	Ca-40 (89%) Ar-40 (11%)	stable

[1] Note: 2.1E+6 = $2.1x10^{+6}$

Table C.1 Radionuclides Included in Generic Soil Screening Analysis

Principal Radionuclide[a]		Associated Decay Chain[b]	Terminal Nuclide or Radionuclide[c]	
Nuclide	Half-life (yr)		Nuclide	Half-life (yr)
Mn-54	0.9	-	Cr-54	stable
Na-22	3	-	Ne-22	stable
Nb-94	20000	-	Mo-94	stable
Ni-59	75000	-	Co-59	stable
Ni-63	100	-	Cu-53	stable
Np-237+D	2100000	Pa-233 (27 d)	U-233	160000
Pa-231	33000	-	Ac-227	22
Pb-210+D	22	Bi-210 (5 d) Po-210 (138 d)	Pb-206	stable
Pm-147	3	-	Sm-147	1.10000e+11
Pu-238	88	-	U-234	240000
Pu-239	24000	-	U-235	700000000
Pu-240	6500	-	U-236	2300000
Pu-241	14	-	Am-241	432 y
Pu-242	380000	-	U-238	4500000000
Pu-244+D	93000000	U-240 ~100%, 14) Np-240	Pu-240	6500
Ra-226+D	1600	Rn-222 (4 d) Po-218 (3 min) Pb-214 (~100%, 27 min) Bi-214 (20 min) Po-214 (~100%, 1 min)	Pb-210	22
Ra-228+D	8	Ac-228 (6 h)	Th-228	2
Ru-106+D	1	Rh-106 (30 s)	Pd-106	stable
Sb-125+D	3	Te-125m (23%, 58 d)	Te-125	stable
Sm-147	110000000000	-	Nd-143	stable
Sm-151	90	-	Eu-151	stable
Sr-90+D	29	Y-90 (64 h)	Zr-90	stable
Tc-99	210000	-	Ru-99	stable
Th-228+D	2	Ra-224 (4 d) Rn-220 (56 s) Po-216 (0.2 s) Pb-212 (11h) Bi-212 (61 min) [Po-212 (64%, 0.3 µs) Tl-208 (36%, 3 min)]	Pb-208	stable
Th-229+D	7300	Ra-225 (15 d) Ac-225 (10 d) Fr-221 (5 min) At-217 (32 ms) Bi-213 (46 min) [Po-213 (98%, 4 µs) Tl-209 (2%, 2 min)] Pd-209 (3 h)	Bi-209	stable
Th-230	77000	-	Ra-226	1600

Table C.1 Radionuclides Included in Generic Soil Screening Analysis

Principal Radionuclide[a]		Associated Decay Chain[b]	Terminal Nuclide or Radionuclide[c]	
Nuclide	Half-life (yr)		Nuclide	Half-life (yr)
Th-232	14000000000	-	Ra-228	6
Tl-204	4	-	Pb-204 (97%) Hg-204 (3%)	stable stable
U-232	72	-	Th-228	2
U-233	160000	-	Th-229	7300
U-234	240000	-	Th-230	80000
U-235+D	700000000	Th-231 (26 h)	Pa-231	34000
U-236	2300000	-	Th-232	14000000000
U-238+D	4500000000	Th-234 (24 d) [Pa-234m (99.8%, 1 min) Pa-234 (0.2%, 7 h)]	U-234	240000
Zn-65	0.7	-	Cu-65	stable

[a] Radionuclides with half-lives greater than six months. "+D" designates principal radionuclides with associated decay chains.
[b] The chain of decay products of a principal radionuclide extending to (but not including) the next principal radionuclide or a stable nuclide. Half-lives are given in parentheses. Branches are indicated by square brackets with branching ratios in parentheses.
[c] The principal radionuclide or stable nuclide that terminates an associated decay chain.
[d] A hyphen indicates that there are no associated decay products.
[e] The branching decay for Pu-241 and Cm-243 involves multiple principal radionuclides and associated radionuclides.

C.2 Soil-water Partition Coefficients for Radionuclides

As with organic chemicals, development of SSLs for inorganics (including radionuclides) requires a soil-water partition coefficient (K_d) for each constituent. However, the simple relationship between soil organic carbon content and sorption observed for organic chemicals does not apply to inorganics (including radionuclides). The soil-water distribution coefficient (K_d) for inorganics (including radionuclides) is affected by numerous geochemical parameters and processes, including pH; sorption to clays, organic matter, iron oxides, and other soil constituents; oxidation/reduction conditions; major ion chemistry; and the chemical form of the radionuclide. The number of significant influencing parameters, their variability in the field, and differences in experimental methods result in as much as seven orders of magnitude variability in measured metal K_d values reported in the literature (see Table 43 in the Soil Screening Guidance: Technical Background Document (EPA 1996b)). This variability makes it much more difficult to derive generic K_d values for metals (including radionuclides) than for organics. Therefore, it is recommended that K_d values be measured for site-specific conditions. If the Kd is not measured site-specifically, then a conservative Kd should be used in calculating SSLs.

Tables C.2a and C.2b list the default K_d values for each element. Table C.2a is derived from the EPA Office of Radiation and Indoor Air's 1999 "Understanding Variation In Partition Coefficient, K_d, Values, Volume 1: The K_d Model of Measurement, And Application Of Chemical Reaction Codes, & Volume 2: Review Of Geochemistry And Available K_d Values For Cadmium, Cesium, Chromium, Lead , Plutonium, Radon, Strontium, Thorium, Tritium, And Uranium". The K_d values in Table C.2a are the most conservative values provided for each element in (EPA 1999). Each of these values are based on the chemical behavior that was considered to provide the most conservative K_d value for that element. Users that have measured pH values at their site that differ from the range given in this report, may want to consult Tables 5.4 to 5.9 in the TBD for alternative K_ds that are still conservative.

The K_d values in Table C.2b are the most conservative values provided by Sheppard and Thibault (Sheppard, 1990) for the remaining elements not addressed in (EPA 1999), that are not based on soil-to-plant transfer. EPA recommends that K_ds based on soil-to-plant uptake data should not be used when estimating migration of contaminants from soil to groundwater.

When estimating migration of contaminants from soil to groundwater for a contaminant which is not represented with a default K_d value in either Table C.2a and C.2b, site decision-makers should develop a site-specific K_d. Site decision-makers also may measure a site-specific K_ds to more accurately estimate contaminant migration rather than using the default values in either Tables C.2a or C.2b or Tables 5.4 to 5.9 in the TBD.

Table C.2a Default K_d Values for Selected Elements

Element	K_d value	Element	K_d value
Cs	10	Sr	1
H	0	Th	20
Pu	5	U	0.4
Rn	0		

Source: EPA, 1999

Table C.2b Sheppard and Thibault's Default K_d Values for Selected Elements

Element	K_d value	Element	K_d value	Element	K_d value
Ac	NDA	Eu	NDA	Pa	NDA
Ag	2.7	Fe	3.1	Pb	6
Am	8.2	Gd	NDA	Pm	NDA
Bi	NDA	I	0.03	Ra	3
C	0.8	K	NDA	Ru	5
Cd	2.7	Mn	4.9	Sb	NDA
Ce	35	Na	NDA	Sm	NDA
Cl	NDA	Nb	NDA	Tc	0.007
Cm	86	Ni	34	Tl	NDA
Co	0.1	Np	0.1	Zn	0.1

Source: Sheppard, 1990

NDA: No Default K_d Available. A K_d for this element must be developed on a site-specific basis to evaluate the potential for fate and transport of this contaminant from the soil to groundwater.

C.3 Soil-to-Plant Transfer Factors

The soil-to-plant transfer factor is defined as the ratio of the concentration of the principal radionuclide in plant in pCi/g to the concentration of the radionuclide in soil in pCi/g. This factor is also known as the plant root uptake factor. The soil-to-plant or soil-to-vegetation transfer factor, for a given type of plant and for a given radionuclide can vary considerably from site to site with season and time after contamination. These variations depend on such factors as the physical and chemical properties of the soil, environmental conditions, and chemical form of the radionuclide in the soil. Furthermore, soil management practices such as ploughing, liming, fertilizing and irrigation can also effect the uptake of radionuclides by vegetation. Readers are referred to the TBD for a discussion of the variability of this parameter. This is a chemical/radionuclide specific parameter. The default values for different radionuclides are presented in Table C.3.

Table C.3 Default Soil-to-Plant Transfer Factors

Elem	TF_p	Elem	TF_p	Elem	TF_p	Elem	TF_p
H	4.8	Cu	0.13	In	0.003	W	0.018
Be	0.004	Zn	0.4	Sn	0.0025	Ir	0.03
C	5.5	Ge	0.4	Sb	0.01	Au	0.1
N	7.5	As	0.08	Te	0.6	Hg	0.38
F	0.02	Se	0.1	I	0.02	Tl	0.2
Na	0.05	Br	0.76	Xe	0	Pb	0.01
Al	0.004	Kr	0	Cs	0.04	Bi	0.1
P	1	Rb	0.13	Ba	0.005	Po	0.001
S	0.6	Sr	0.3	La	0.0025	Rn	0
Cl	20	Y	0.0025	Ce	0.002	Ra	0.04
Ar	0	Zr	0.001	Pr	0.0025	Ac	0.0025
K	0.3	Nb	0.01	Nd	0.0024	Th	0.001
Ca	0.5	Mo	0.13	Pm	0.0025	Pa	0.01
Sc	0.002	Tc	5	Sm	0.0025	U	0.0025
Cr	0	Ru	0.03	Eu	0.0025	Np	0.02
Mn	0.3	Rh	0.13	Gd	0.0025	Pu	0.001
Fe	0.001	Pd	0.1	Tb	0.0026	Am	0.001
Co	0.08	Ag	0.15	Ho	0.0026	Cm	0.001
Ni	0.05	Cd	0.3	Ta	0.02	Cf	0.001

Source: ANL, 1993.